INTEGRATING PEDESTRIAN AND BICYCLE FACTORS INTO REGIONAL TRANSPORTATION PLANNING MODELS: SUMMARY OF THE STATE-OF-THE ART AND SUGGESTED STEPS FORWARD

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I. Overview

In the past several years, there has been growing public support for improvements to the quality of the pedestrian and bicycle environment, expressed in sharply higher investment in projects encouraging of such travel. Many local, regional, and state authorities are beginning to pay attention to how non-motorized transportation can help address community problems with traffic congestion, air quality, health, safety, and the vitality of neighborhood commercial areas. Intermodal Surface Transportation Efficiency Act (ISTEA) and the transportation conformity provisions of the Clean Air Act also have provided support for these local initiatives by providing funding flexibility and encouraging investments and policies that reduce the need for motor vehicle travel.

The regional transportation and air quality planning requirements established under these laws promote greater consideration and encouragement of non-motorized travel options as part of Major Investment Studies, as well as in regional and state transportation plans and programs. In areas with serious air quality problems, the emission impacts of transportation plans and programs must be evaluated to assure contributions towards healthier air.

However, evaluating the effects of bicycle/pedestrian infrastructure and programs on travel behavior and emissions is in general a poorly developed science. Traditional travel demand and supply models for metropolitan planning have ignored walking and bicycles as travel modes. Little data have been collected on non-motorized travel and the factors that influence whether people find walking or bicycling to be a viable option. Hence, where bicycle/pedestrian projects have been evaluated, ad hoc techniques have been used, often without a good empirical basis. In most cases, these analyses have had serious deficiencies and have lacked sensitivity to multiple factors that are important determinants of travel behavior. This has led to serious mis-estimation of emission and travel impacts and frequently impeded adoption of sound plans and policies sought by the public and a growing number of elected officials. Reform of these analytic techniques should be a high priority in the transportation planning and engineering community.

This paper reviews typical techniques in use today for estimating the travel behavior effects of bicycle and pedestrian facilities and programs and other factors that influence use of non-motorized travel modes and offers suggestions for near-term advances in the state-of-the-art and state-of-the-practice.

II. Current Modeling Practices

There are several principal approaches that have been used to evaluate the effects of transportation policies and infrastructure on bicycle and pedestrian travel. Some analysts have used regression analysis to relate aggregate travel behavior to other transportation and land use data. Others have used market-share diversion analysis to evaluate potential diversion of automobile trips to walk and bike, usually assuming varying modal diversion based on trip length, with fixed trip distributions. The third and most robust approach is discrete choice analysis, either based on aggregate or disaggregate data. In practice, inadequacies of both data and modeling frameworks have led to less than satisfactory performance for all of these methods in the American metropolitan planning context, although the latter approach offers the greatest promise for refinement.

Experience in cities such as Davis, California, and Copenhagen, Denmark, show that reallocation of street space and development of comprehensive cycling networks can have a profound effect in diverting car trips to the bicycle and that bicycle access can promote dramatic expansion of transit catchment areas. In Copenhagen, a city of 1.7 million people, road building was abandoned in the early 1970s, large numbers of bus priority lanes were introduced, and a comprehensive network of segregated cycle paths built. The result was a 10% fall in traffic since 1970 and an 80% increase in the use of bicycles since 1980. About one-third of commuters now use cars, one-third public transport, and one-third bicycles. Cycling accidents have decreased slightly, despite the increase in mileage, because of the network of cycle paths, which in many cases were created by reallocating arterial street space from cars.[1] Had Copenhagen embarked on major highway expansions in recent decades, surely energy use and emissions would be far higher than they are today. If the transportation models and methods common to most U.S. metropolitan regions today were used to evaluate the effects of Copenhagen's policies, they would not just underestimate the emission benefits of these policies, they would predict the exact opposite of the real world effect of these policies, producing dire forecasts of sharply higher air pollution emissions and traffic congestion.

The effect of restructuring street space in the context of other supportive transportation and land use policies is not just a European phenomenon. Indeed, in Davis, California, the share of trips made by bicycle has experienced comparable growth in the same period in response to conscious public policy choices. Davis, California, a town of 50,000 people near Sacramento, illustrates a successful full traffic cell system which has cut highway capacity significantly in the vicinity of the University of California and town center to increase walk and bicycle use. Bicycle use grew sharply in the 1960s, leading to election of a pro-bikeway City Council in 1966. Demonstration bikelanes proved popular and were quickly extended. In addition to the UC Davis traffic cell and bicycle network, the City of Davis now has 37 miles of bicycle lanes and 29 miles of bicycle paths in an interconnected network. Parking is limited and costs drivers on the UC Davis campus. Bus, van, and commuter rail services offer other alternatives to the automobile. Davis has prohibited development of shopping centers near the freeway, retaining a vibrant pedestrian-oriented downtown commercial area. As a result, 27% of UC

Davis employees and 53% of UC Davis students use bicycles as their primary commute mode. Of those who live and work in Davis, 44% bicycle to work. The City Planning Department estimates that 25% of all person trips in the city are by bicycle. Walk shares in the city are also high—on the order of 10-20%. Clearly air pollution and traffic have been reduced by restricting and reducing highway capacity in Davis.

Yet even with the best currently used approach to incorporating pedestrian and bicycle friendliness into regional transportation models, the Sacramento regional travel model must include a special geographic variable for Davis to match the observed use of non-motorized modes, which far exceeds what the model would otherwise predict. Clearly, there is need for more research and model development to produce satisfactory analysis tools sensitive to the effects of factors influencing non-motorized travel. Until these are developed, air quality and transportation evaluation, congestion management systems, and community and regional planning work dependent on computer transportation models will at best ignore or underestimate the potential for reintegrating walking and bicycling into American communities.

A. Regression Analysis

The simplest approach to evaluating non-motorized mode potential is to use regression analysis against recent aggregate data. An example of this approach is work done by a consultant to Pennsylvania DOT, which has since been adapted by CATS, the Chicago area Metropolitan Planning Organization (MPO), to Illinois. This approach is characterized by relating observed aggregate bicycle use data at the jurisdiction level (usually Census Journey-to-Work bike or walk mode share) to other aggregate variables, such as residential density, characteristic topography of towns, or metropolitan area size. A presentation of this approach was made at the 1995 Transportation Research Board meeting in Washington, D.C.

This highly aggregate nature of this approach makes it useful principally for first-stage research evaluating factors that may influence differences in travel modal dependencies in different regions. This approach is less useful for project or program evaluation, since it generally just describes the current gross patterns of observed travel behavior in different places.

B. Market-Share Diversion Analysis

This approach is characterized by evaluation of trip-length distributions by mode and the use of analyst judgement to make assumptions about potential mode switching that might be induced by a policy/investment change. This approach can be applied in a more or less rigorous manner in defining the market potentially affected by a facility or policy. Unfortunately, with this method, the sometimes questionable judgement of the transportation analyst can lead to poor estimates of program or project effects.

Several recent evaluations have used this approach. A typical case is work done by a consultant for the Metropolitan Washington Council of Governments (WashCOG). [2] Without supporting evidence, the analyst evaluating the Bicycle Element of the WashCOG Long-Range Transportation Plan assumed that the plan would have no effect on trip distribution and would produce no reduction in non-work vehicle travel, with only minimal diversion of work trips.[a] These assumptions were made despite the plan's explicit objective of producing a 5% mode share for bicycles in the year 2000. Applying a simple market-share diversion analysis, the analyst concluded the plan would produce a less than 0.15% change in total regional trips. It is not surprising that the resulting estimate of cost-effectiveness of this bicycle plan was very low, at $66,500 per ton of Volatile Organic Compound (VOC) reduction. Not only were the estimated travel demand effects low-balled by completely ignoring non-work travel reductions and understating potential work travel impacts, but the same analyst assumed these facilities operated only 250 days a year and significantly underestimated the facility life at 10 years. Other analysts making empirically defensible assumptions different than these could estimate the cost effectiveness to be as much as twenty times greater. Unfortunately, this analysis was buried in a mass of other evaluations and the underlying assumptions went generally unquestioned. This work made use of simple graphical analysis tools and selected aggregate outputs from the regional MINUTP-based transportation model.

Another example of market share diversion analysis is work done by Stuart Goldsmith of the Seattle Engineering Department,[3] which is being used as a model by some other bicycle planners, for example in Portland, Oregon. This work evaluated a specific set of bicycle lanes based on the geographically specific travel market area they would affect, estimating the number of potential bicycle commuters using stated preference (SP) survey data on the number of people who said safer bicycle facilities would encourage them to bicycle commute. Non-work Single Occupant Vehicle (SOV) trips diverted to utilitarian bicycle trips by the bicycle lanes were also estimated using data on market shed, the share of residents owning bicycles, the share of these individuals using their bicycles for utilitarian trips, SP survey data on effects of safer facilities, and assumptions about modal substitution and trip length. This work has made use of spreadsheet software for development and implementation, complemented by data from the regional travel demand models, coded and implemented in EMME/2. While more sophisticated than the analysis for WashCOG, this approach still ignores the potential for altering trip destination choice, synergism with other travel demand management strategies or even anticipated increases in roadway congestion.

As a quick analysis technique, this approach can produce reasonable results if the analyst makes appropriate assumptions, but it cannot easily account for potential changes in the spatial distribution of trip ends and trip length distribution that major changes in pedestrian and bicycle

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[a] The analyst assumed at most a 10% increase in the share of Home Based Work walk/bike trips less than one mile, an 8% increase in the share of HBW walk/bike trips 1-2 miles length, a 4-6% increase for 2-4 mile trips, a 1-2% increase for 4-6 mile trips, and no change in travel for longer work trips.

friendliness and other strong travel demand management strategies can induce, nor for changes in time-of-day of travel. Thus, this approach is destined to remain in the realm of sketch planning.

C. Discrete Choice Modeling

This approach recognizes the potential of walking and bicycling as legitimate forms of travel and seeks to integrate these modes into conventional regional transportation planning models. The best of these efforts have used indicators of pedestrian/bicycle friendliness along with fuller information on alternative regional transportation choices. In time, first stage qualitative indicators are being replaced by more rigorously measured quantitative factors, often estimated by use of geographic information systems (GIS), stated preference surveys, and other techniques.

In most U.S. cities, transportation models consider only travel time and cost of competing modes, ignoring the quality of the pedestrian and cycling environment and frequently treating the proximity of jobs and households to transit in at best crude manner. However, recent research and model development in several regions provides strong evidence that transportation modelers can improve their model's abilities to replicate observed travel patterns and behavior by including more indicators of pedestrian and bicycle friendliness. Such enhancement provides more defensible and policy sensitive analysis of air quality effects of transportation plans and programs than ad hoc methods used elsewhere.

A small but growing number of planning agencies in the U.S., Europe, and Asia have developed regional travel demand models that represent pedestrian and/or bicycle friendliness through qualitative or quantitative indicators, making these tools somewhat policy-sensitive to the potential for improvements in pedestrian and/or bicycle facilities and related community design elements. These include the Maryland-National Capital Park and Planning Commission (M-NCPPC) in Montgomery County, Maryland; METRO, the regional government in Portland, Oregon; the Sacramento Area Council of Governments in California; and regional planning agencies in Sweden and Shanghai, China.

Montgomery County's Pedestrian Friendliness Index. The M-NCPPC in Montgomery County, Maryland, a municipality of 750,000 people immediately north of Washington, D.C., in 1987 developed a Pedestrian and Bicycle Friendliness Index (PFI) as part of an AM peak hour work trip logit mode choice model. This index is a score independently assigned to all traffic zones in the region based on the availability of sidewalks, bicycle paths, and bus stop shelters, the extent of building set-backs from the street, and the heterogeneity of land use at a local level. [4] This index was found to be highly statistically significant and explained much of the variation in auto-transit mode choice not accounted for by another mode choice model which focused solely on travel time and cost factors, ignoring transit access conditions at the home and workplace trip ends. The index was used with travel distance data to develop a crude walk/bike mode choice model. This model was coded and run using the EMME/2 software package.

To reflect the likely effects of alternative pedestrian- and transit-oriented development scenario as part of the Montgomery County Comprehensive Growth Policy Study, M-NCPPC analysts made several adjustments to the model inputs. They assumed that in the most pedestrian-friendly central areas the PFI might increase above the maximum level of 0.5-0.6 assumed to exist in the Washington, D.C. region in the late 1980s, to a future level of as high as 0.8. This was thought to represent a key part of the effect of possible traffic calming and development of limited automobile restricted downtown areas. Walk egress times in these areas were also increased from 2 to 5 minutes to reflect scarcer parking and automobile limitations. Automobile ownership levels were adjusted slightly downwards from 1985 levels in zones assumed to have much higher levels of transit, walk, and bicycle access in the future. This contrasted with slight further growth in household automobile ownership levels projected for a trend scenario. In evaluating the trend scenario, the PFI and automobile egress times were held constant at 1985 levels. The study concluded on the basis of extensive modeling and evaluation that the county would face unacceptable growth in peak traffic congestion if planned growth patterns were followed, even at slower growth rates, unless measures were taken to orient future growth around an expanded transit network, to improve pedestrian and bicycle friendliness, and to shift commuter subsidies and pricing policies to favor alternatives to single occupant vehicle travel.

To support initiatives to increase sidewalk construction and more fully incorporate the needs of pedestrians into transportation planning, the Montgomery County Planning Department (MCPD) developed a computerized geographic information system (GIS) database on side- walks. [5] These data have been used in the county's efforts in growth management, master planning, transportation analysis, and capital improvements planning. Until the development of the Montgomery County sidewalk database, there was only limited and fragmentary information available on where sidewalks existed and where they were lacking across the county. A quick and low-cost comprehensive survey, collected by two summer interns who spent 6 weeks driving on nearly every road in the county, provided raw data for the inventory. These interns marked up small-scale street maps with a dozen colors of ink to code each road segment for the presence or absence of sidewalks on one or both sides of the street, sidewalk width (under or over three feet), and the presence or absence of a buffer between street and sidewalk (of under or over three feet), and open vs. closed road sections. With this data, GIS software was used to produce maps of roads by sidewalk status at various scales of resolution, as well as sorted listings of street blocks by sidewalk classification. The foundation of the database is the TIGER file used to enumerate households in the 1990 U.S. Census, a low-cost product available from the Census Bureau, which describes nearly all roads in the U.S. The inventory revealed that nearly 60% of the road links in the County have no sidewalks and only 37% of road links have sidewalks on both sides of the street, and that there is wide variation in the availability of sidewalks in different parts of the County. The sidewalk ratio was found to be a statistically significant factor in explaining whether people walk-to-transit, drive-to-transit, or drive a car to work, and is being used in Montgomery County's latest transportation forecasting models.

Portland METRO's PEF. A Pedestrian Environment Factor (PEF) is being used in transportation modeling in Portland, Oregon, by the METRO planning agency. The PEF was defined by local planners who scored each zone on a 1 to 3 scale for sidewalk continuity, ease of street crossings, local street characteristics (grid vs. cul-de-sac), and topography. These were summed to indicate overall pedestrian environment conditions, with scores ranging from 4 (poor) to 12 (good). The PEF proved to be a significant factor in determining automobile ownership, which itself is a powerful factor influencing transit ridership. It was found that in an area where walk trips can be more easily made, the need for an automobile is less. The use of the PEF also improved the ability of Portland's mode choice models to estimate walk and transit trips. Residential and employment density and proximity factors, such as retail employment within one mile, enter into Portland's models separate from the PEF and are also important indicators of mode choice and automobile ownership.[6] This model was coded and run using the EMME/2 software package.

A major foundation and FHWA-sponsored study, "Making the Land Use Transportation Air Quality Connection," (LUTRAQ) developed and used this enhanced transportation model to evaluate a proposed western bypass highway around the west side of Portland, Oregon, vs. a transit and pedestrian oriented development alternative. This study showed that transit and pedestrian oriented urban design and infill development and the retrofit of pedestrian improvements to automobile-oriented suburbs can have significant effects on travel behavior sufficient to eliminate the need to build new ring freeways, particularly when reinforced by sensible economic and pricing incentives, such as modest parking charges and reduced transit fares that begin to level the playing field between travel modes. Total vehicle trips per household in the TODs were 6.05 per day, compared to 7.09 outside the TODs under the LUTRAQ scenario and 7.7 with either the Bypass or No Action alternative. The LUTRAQ scenario reduced VMT in the study area by almost 14% compared with the Bypass alternative and reduced Vehicle Hours of Travel in the PM peak hour by almost 8%. Even greater effects on travel behavior can be expected when these measures are combined with bicycle improvements, stronger economic incentives, more effective parking management, introduction of neighborhood vehicles, and further shifts in land use policies to favor infill housing and commercial development. The LUTRAQ analysis indicated these Transportation Demand Management (TDM) measures accounted for about 30% of the increase in non-automobile driver mode shares for all trips and about 55% of the increase in non-automobile work trip mode shares, not counting the corrections for underestimated walk trips, which would further increase the effects of the design measures.[7]

The LUTRAQ model incorporated measures of pedestrian friendliness but underestimated the potential to shift short car trips to pedestrian trips. This was due to acknowledged under-reporting of walk trips in the 1985 Portland household travel survey data[8] and the assumption that nowhere in the region would pedestrian friendliness be better than it is today in downtown Portland (i.e. the maximum PEF was set to 12). Clearly, Portland neighborhoods could become far more pedestrian friendly than observed today. The underestimation of walk/bike trips was also a function of the lack of integration of the pedestrian mode choice model with the auto/transit mode choice model—pedestrian trips are subtracted out of total person trips in a "pre-mode-choice" model step even in the enhanced LUTRAQ model. Thus, while pricing and other TDM measures could divert auto trips to transit or ridesharing, these pricing and TDM measures played no role in the walk or bike mode choice estimation process, which clearly should be sensitive to such things as parking cost and availability, especially for shorter trips. Despite these shortcomings, the LUTRAQ analysis showed that modest improvement in the quality of the pedestrian environment alone could reduce the Vehicle Miles of Travel in suburban zones by about 10%. Variation in building orientation at the zonal level was also found to account for changes of 10% or more in VMT per household.[9]

The LUTRAQ model was unable to reflect potential improvement of bicycle friendliness, bicycle access to transit, or encouraging bicycle use, due to the lack of available local empirical data. The Portland, Oregon, regional government (Metro) is moving forward to develop GIS-based methods for incorporating additional pedestrian and bicycle related factors into their long range planning analyses.

Sacramento Model. SACOG's model was developed in 1994, based to a significant degree on the Portland, Oregon, model, and incorporates a Pedestrian Environment Factor (PEF). This model was coded and run using the MINUTP software package. It is notable that this model would substantially underestimate non-motorized travel in the region's most bicycle and pedestrian friendly center, Davis, where almost one in three trips is by bicycle, were it not for the inclusion of a special "Davis factor." This highly significant binary variable is applied only to the satellite city of Davis, 20 miles from downtown Sacramento, in order to "correct" for that town's special conditions. One key factor may be the "traffic cell" that has been created in Davis, which forces car traffic to travel circuitously around the central area while allowing direct connections on a very high quality bicycle and pedestrian network on the UC Davis campus, which is the major employment center. Other likely key factors are the extensive separated bikeway network that extends throughout the town, the bicycle-friendly climate of opinion in Davis, the parking pricing and parking management systems, and the zoning restrictions that have minimized freeway/automobile-oriented retail development and preserved the town center's business district. These factors could and should be evaluated in further model refinement, using available Geographic Information System (GIS) and travel survey data.[10]

Experience Outside the U.S. Many European regional models include walk and bicycle travel in a basic way. While many Dutch modelers have developed bicycle network traffic assignments to support bikeway planning, the development of infrastructure sensitive demand models is less well established. Some work in Rotterdam has been reported to this author, but documentation is not readily available.

Many German models, for example all of those developed using the VISEM (TRIPS) software (now also being marketed in the US), explicitly account for walk and bicycle trips in trip estimation, but do not generally deal with bicycle traffic assignment, and deal with walk assignment only in central pedestrian oriented areas. VISEM is an activity chain based traffic demand model that considers the relative frequency of distances by mode of transportation for seven different groups of tripmakers (employees vs. nonemployed, with or without cars; students above vs. below 18 years age; and apprentices), but recommends use of local survey data to calibrate maximum likelihood estimates for these values. Applications of VISEM have not to date included a supply quality variable for pedestrian or bicycle travel, although the model structure could be adapted to this. VISEM's developers suggest that improved bicycle facilities or safety measures for non-motorized travel might be reflected in their model structure through modification of logit model parameters, changes to the access and egress times of the affected zones, and changes in the coding of mode speed or travel time for specific origin-destination pairs. Indeed, these same approaches could be used in most conventional U.S. transportation models that explicitly include non-motorized travel modes and their attributes.[11]

Some Swedish regional transportation models, for example some developed by Stephan Algers of Transek AB, include travel demand models for bicycles as a separate travel mode. As of several years ago, this was a simple model where the share of trips between an origin and destination by bicycle was a function of distance and the share of the trip that could be made on separate bicycle facilities, among other factors, in a nested logit model. Many of these models are coded and run using the EMME/2 software package.

In Shanghai, China, Barton-Aschman and INRO consultants collaborated to develop a bicycle network and travel demand model to evaluate transportation plans and projects in the framework of EMME/2 software in the mid and late 1980s. Bicycle travel demand was a function of trip distance, time, and several other factors as part of what this author believes was an otherwise typically structured four step travel demand model with logit mode choice, with separate bicycle, automobile, and transit trip assignments to the network.

III. Modeling Emission Impacts of Factors Influencing Pedestrian and Bicycle Travel

Problems in evaluating the travel behavior effects of factors influencing walking and bicycling are compounded when conventional emission factor models are used to evaluate some of these strategies. In America, most evaluation of mobile source emissions relies on Environmental Protection Agency (EPA's) MOBILE model or EMFACT, the California equivalent. These models depend on speed factor adjustment curves to evaluate how emissions will change with changes in vehicle operating speed. However, recent research by EPA and the California Air Resources Board indicates that these speed factor adjustment curves are not very robust and frequently lead to improper estimates of emission changes. This is a particular problem in the evaluation of some measures supportive of walking and bicycling, such as traffic calming and traffic cells, which since the 1970s have become widespread in Europe and are beginning to take greater root in the U.S.

Traffic calming encompasses a wide range of techniques for slowing down motor vehicle traffic to provide an environment more supportive of walking and bicycling and safer for children, the elderly, and others. Traffic calming measures include narrowing roadways, reducing speed limits, introducing curvilinear elements in formerly straight street to slow traffic, and changing the vertical profile of the street with elements such as raised intersection tables for pedestrian and bicycle path crossings. Although the EPA MOBILE model would indicate that slowing down traffic typically increases emissions, empirical research indicates the opposite in many cases. Research in Germany has shown that the greater the speed of vehicles in built-up areas, the higher is the incidence of acceleration, deceleration and braking, all of which increase air pollution. German research indicates that traffic calming reduces idle times by 15%, gear changing by 12%, brake use by 14%, and gasoline use by 12%. [12] This slower and calmer style of driving reduces emissions, as demonstrated by an evaluation in Buxtehude, Germany. The table below shows the relative change in emissions and fuel use when the speed limit is cut from 50 km/h (30 mph) to 30 km/h (20 mph), for two different driving styles. Even aggressive driving under the slower speed limit produces lower emissions (but higher fuel use) than under the higher speed limit, although calm driving produces greater reductions for most emissions and net fuel savings.[13]

Moreover, by encouraging more use of walking and bicycling and reducing the advantage offered by the automobile for short trips relative to these alternatives, traffic calming usually reduces the number of trips, trip starts, and VMT. Applied on a widespread basis in conjunction with transit improvements and transportation pricing changes, traffic calming may contribute as well to a reduction in household automobile ownership levels, further reducing emissions and travel demand. Thus, even in circumstances where individual vehicle emissions per mile traveled increase due to more aggressive acceleration, braking, and use of second gear, traffic calming will likely lead to overall emission reductions due to its influence on travel demand.

A recent FHWA report discusses the German experience with traffic calming in six cities and towns in the early 1980s:

Change in Vehicle Emissions and Fuel Use with Speed Change from 50 km/h to 30 km/h

Emission Type	Driving Style	
	2nd Gear Aggressive	3rd Gear Calm
CO	-17%	-13%
HC	-10%	-22%
NOx	-32%	-48%
Fuel Use	+7%	-7%

"The initial reports showed that with a reduction of speed from 37 km/h (23 mph) to 20 km/h (12 mph), traffic volume remained constant, but there was a 60% decrease in injuries, and a 43% to 53% reduction in fatalities. Air pollution decreased between 10% and 50%. The German Auto Club, skeptical of the official results, did their own research which showed broad acceptance after initial opposition by the motorists. Interviews of residents and motorists in the traffic calmed areas showed that the percentage of motorists who considered a 30 km/h (18 mph) speed limit acceptable grew from 27% before implementation to 67% after implementation, while the percentage of receptive residents grew from 30% to 75%."[14]

This experience of initial skepticism of traffic calming, followed by its widespread popularity after implementation, has been experienced in hundreds of communities across Europe, Japan, and Australia, along with the few U.S. communities which have adopted such strategies, such as Palo Alto, California, and Seattle, Washington. Unfortunately, most U.S. transportation models and evaluation methods are ill-suited to reflect these empirical effects. Work is needed by EPA and others to evaluate traffic calming effects on emissions and travel behavior in varied American community settings.

Many places in Europe and Japan—from cities like Göteborg, Sweden, and Hannover, Germany to Osaka, Japan, from suburban new towns such as Houten, Netherlands, to established automobile-oriented suburban centers like Davis, California—have successfully implemented traffic cell systems. These typically consist of a set of radial pedestrian, bicycle, and transit-only streets focused on a central area. While pedestrians, bicyclists, and public transportation can freely cross these streets, automobile traffic cannot, but must instead use a ring road around the center. Traffic cell systems are very effective at eliminating through traffic in central areas and shifting short automobile trips in the central area to walking, bicycling, and public transportation, significantly reducing cold start and evaporative emissions. By reducing central area traffic and increasing street space dedicated to walking, bicycling, and public transportation, these alternatives become more attractive and parking requirements in the central area diminish. Success in reducing environmental impacts is dependent on curbing automobile-oriented peripheral development.

Göteborg, Sweden, introduced traffic cells in mid-1970s together with priority for public transport at signals, new suburb-to-downtown express bus service, and central area parking controls. Traffic accidents were reduced 36%, noise was cut from 74 to 67 db in the main shopping street, peak CO levels dropped 9%, 17% fewer cars entered the center city, weekday transit trips to the center were up 6%, traffic on the inner ring road was up 25%, and the costs of running public transport went down 2%. Nagoya, Japan, introduced traffic cells in residential areas in the mid 1970s, together with computer managed signal system, bus lanes, bus priority at signals, staggered work hours, and parking regulation. This resulted in a 17% increase in traffic speeds on main roads covered by the signal system, a 3% increase in bus ridership. Traffic deaths in traffic cell areas fell 58%, 15% fewer cars entered the central area in the morning peak, and auto-related air pollution decreased by 16%.[15]

The Downtown Crossing pedestrian zone, in Boston, Massachusetts, is a limited traffic cell serving a core area with 125,000 employees. Eleven blocks of the central business district were closed to traffic in 1978, while steps were taken to improve transit service and parking management. In the first year, there was a 5% increase in visitors to the area, a 19% increase in weekday shop purchases, a 30% increase in weeknight purchases, an 11% increase in Saturday purchases, a 21% increase in walking trips to the area, a 6% increase in transit trips to the area, a 38% decrease in auto trips to the area, and no increase in traffic congestion on adjacent streets, thanks to elimination of on-street parking and stricter parking enforcement on nearby traffic streets.

Clearly, more research is needed on how to incorporate strategies like traffic cells and traffic calming into regional transportation models. DOT and EPA, along with local, regional, and state agencies, should cooperate in advancing our knowledge in this area and integrating into mainstream planning and program evaluation practices.

IV. Measuring Bicycle Friendliness

In the past several years, some analysts have worked to develop indicators of bicycle Level of Service (LOS), bicycle friendliness, bicycle stress level, bicycle suitability of streets, and the like. Some of these have been used to help create consumer-oriented bicycle maps, while others have been developed for modeling and facility need identification purposes. Bruce Epperson, a Senior Transportation Planner at the Miami Urbanized Area MPO, recently summarized much of this research.[16] However, little of this work has been integrated with regional travel demand model development.

Alex Sorton, at Northwestern University Traffic Institute, and Tom Walsh, from Madison, Wisconsin, DOT, have developed the concept of "stress levels" to estimate the relative compatibility of roadways and different types of bicyclists. Their stress level index, ranging from 1 to 5, is based on curb-lane traffic volume, motor-vehicle speed, and curb-lane width, using peak period traffic conditions.[17] This stress level model is already being used in several cities, including Arlington, Texas, and Bloomington, Indiana. FHWA has funded a two-year research project to validate this method, using videotaping and cyclist ratings. In a project for the Regional Transit Authority in Chicago, a consultant team headed by Wilbur Smith Associates, that includes Allan Greenberg of the League of American Bicyclists and others, is exploring use of videotape and a combination of revealed and stated preference surveys to evaluate bicycle friendliness to help estimate the potential for bike-and-ride access to rail stations and other transit as part of a nested logit model. A key challenge will be how to relate these measures to discrete travel behavior choice in the broader context of all travel choices and to develop low-cost methods for estimating bicycle stress and related factors across an entire region. Unfortunately, the study does not appear to include measures of the potential response to guarded bicycle parking at stations, although this has superior characteristics to both bicycle racks and lockers and is the most commonly used type of rail station bicycle parking found in the European and Japanese communities where bicycles are the predominant access mode to express transit.

Measures of bicycle and pedestrian "friendliness" are essentially measures of the utility offered by these modes in different contexts. It is difficult to come up with simple but consistent measures that can apply to the wide range of travelers who under varying conditions might choose or not to use a bicycle or to increase their propensity to walk. Market choice modeling techniques provide valuable tools to measure the significance of various factors in explaining travel behavior, including traveler response to changes in the pedestrian and bicycle environment and the larger transportation and land use system.

A *Data Collection Case Study of Portland, Oregon*, is to be prepared with support from the federal Travel Model Improvement Program to illustrate the application of leading edge, state-of-the-practice data collection to develop transportation models, including non-motorized modes.[18] However, further research focused more specifically on how to measure non-motorized transportation utility factors and their variance among different types of travelers will be needed to advance cost-effective data collection and model development in a greater number of regions.

X. Recommended Steps Forward

There is a critical need for improved analysis tools to evaluate the effects of bicycle and pedestrian projects and programs on travel demand and how these interact with broader changes in transportation system performance and costs, land use, and urban design. There is a paradigm shift underway in transportation modeling, with a shift away from aggregate analysis of motor vehicle travel towards discrete choice models based on microsimulation of activities and time use. The new paradigm seeks to consider the entire spectrum of travel modes, time-of-day of travel effects, trip chaining, life-cycle effects, urban design factors, pricing sensitivity, and the potential for communications and information systems to affect travel choices.[19] The Federal Travel Model Improvement Program (TMIP), coordinated by the Texas Transportation Institute with DOT and EPA funding, has since 1993 been supporting research on new modeling techniques and training for transportation modelers. TMIP has recognized the need to integrate non-motorized travel into model development and research and has documented some of the U.S. experience with this. However, it has not undertaken any projects designed to advance the state-of-the-art in this area.

TMIP's advanced model development track is focused on the TRANSIMS simulation model development at Los Alamos National Lab, using supercomputers to do advanced microsimulation of activities, travel behavior, and emissions. It is important that this work fulfill its early promise to incorporate explicit representations of walking and bicycling and the environmental factors shaping use of these modes. There has not been evidence of such progress to date, but the project is still only two years into its five year work program and a practical applied modeling system is still some time off. DOT should ensure that this element is integrated into TRANSIMS and shows progress in the coming year. The involvement of an expert in non-motorized transportation modeling as a subconsultant to this project should be sought to ensure that a sound approach is taken in this important research and development project. TRANSIMS elements should be tested in the context of a community where substantially higher than typical use of non-motorized modes is in current evidence to give a suitable empirical basis for development of these model elements. Current TRANSIMS testing in the Dallas-Fort Worth region is not satisfactory in meeting this requirement. Progress in TRANSIMS to date appears to be imbalanced, focusing early applications on traffic simulation while activity analysis and system elements for multi-modal evaluation appear to be lagging. This is of growing concern to the environmental community and should be addressed by the TMIP program managers and Los Alamos.

An immediate priority should thus be for the demonstration of advanced state-of-the-art travel models with substantially greater inclusion of pedestrian/bicycle travel factors, working in one or more regions where data and agency interest can support rapid and efficient progress. While several planning agencies and researchers are interested in developing improved models sensitive to pedestrian and bicycle friendliness factors, progress has been limited by a lack of funding for pilot projects with such a specific objective.

Unfortunately, at many other planning agencies, transportation modelers continue to regard the inclusion of pedestrian and bicycle travel and factors in regional models as a longer term objective to satisfy pressures from stakeholder groups, not as something vital to address in current model refinement work. It is important that federal research funding not focus solely on how to advance the state-of-the-art, but also on how to quickly improve the unacceptable current transportation modeling practices that commonly ignore or unfairly disparage the potential for pedestrian and bicycle programs to make cost-effective contributions to improved air quality, traffic congestion relief, and traffic safety. Thus, a second, related area for research funding should also be immediately pursued. This track should develop and document methods for near-term improvement and disseminate them to modeling practitioners.

As the advanced modeling track progresses, it will provide empirical support for further development of the quick-fix modeling track and integration of these two approaches. It would be desirable to support coordinated advanced travel model development work in two or more regions concurrently to help assure progress in this area of travel model improvement and to provide the basis for later estimating much refined multi-region models using logit coefficient scaling techniques. Longer term diffusion of these pedestrian/bicycle sensitive models will be accelerated if transferable multi-region modeling techniques are developed for both sketch analysis and more detailed evaluation systems. Once a new generation of advanced travel models has been developed with broader sensitivity to factors that can be measured using GIS techniques and data, it should be possible to calibrate on these data sets refined sketch models that build on the quick-response methods and surrogate data sets used in the quick-fix track. This offers promise for improving the transferability of models between regions.

On the basis of this review, two specific and inter-related areas of work are recommended as immediate high priorities for research, development, and demonstration funding, one to advance the state-of-the-art in several regions where adequate data and model development expertise is readily available and the other to provide more typical regional planning agencies with improved, policy-sensitive quick-response analysis methods that can be readily adopted anywhere.

A. Advanced Regional Models Integrating Non-Motorized Modes and Factors

This work would support data development and analysis of factors related to pedestrian and bicycle friendliness and the use of these factors in estimation of new regional travel models. This work should be undertaken in one or more regions with a recent or about to be collected household travel/activity survey. The survey should include a significant sample of walking and bicycle trips. The region should have an established GIS that could support estimation of measures of pedestrian and bicycle friendliness, and should display a variety of environments for walking and bicycling. Model development should examine sensitivity of travel demand, both motorized and non-motorized, to changes in street allocation and design, traffic conditions, land use density and mix, transportation pricing, demographics, topography, and other factors. Street address/intersection GIS-based georeferencing of household and employer-based travel survey records, along with the use of real estate parcel databases and TIGER-based inventories of bus stops and pedestrian/bicycle systems can enable relatively inexpensive examination of the influence of pedestrian and bicycle environmental quality and urban design on travel behavior, and interaction with other factors.[20]

There are several transportation planning agencies that have such datasets which could be linked to estimate such pedestrian/bicycle sensitive travel demand models and where there is strong potential interest in developing such tools, particularly if funding is available for additional consultant and staff time support. These include:

- **Sacramento, California.** Dr. Robert Johnston, at the University of California/Davis, has worked extensively with the new SACOG model and is developing a GIS-based land use/transportation model (TRANUS) for the Sacramento region. Gordon Gery, SACOG's chief modeler, is also interested in exploring ways to improve the agency's model to non-motorized travel factors. There is a recent Sacramento regional travel survey including 4000 households, which has been cleaned up by several people, including Greig Harvey, who examined every individual record for surveyor and respondent errors. A smaller 2400 household sample drawn from this survey, which includes only households reporting income and ages, is used for auto ownership and mode choice model development. A 1994 on-board transit survey supplements this. Work in this region would likely focus on improving and advancing the classical "four-step" transportation modeling process.

- **Portland, Oregon.** Keith Lawton, Deputy Director of Planning at Portland Metro, has recently managed the collection of state-of-the-art household activity surveys throughout the Portland region and Willamette Valley, including Eugene, Oregon, which exhibits high levels of bicycling. He has collected data on 440 bicycle trips out of 2200 households in the Portland region, and observed a 9% walk mode share for total travel (with variance from 5% to 29% of trips between different areas of the region). This 1994 survey data are now undergoing detailed cleaning and analysis for model development work in 1995-96. Metro has already begun to evaluate indicator variables using a GIS to replace the cruder Pedestrian Environment Factor. Metro's next generation models will likely represent a transitional approach that incorporates many of the elements of activity analysis and microsimulation, while retaining some of the framework of more classical methods.

- **Boston, Massachusetts.** John Bowman, a Ph.D. candidate at Massachusetts Institute of Technology and a student of Moshe Ben-Akiva, who is a leader in the field of discrete choice modeling theory and applications, in early 1995 developed a proposal for advanced modeling methods sensitive to pedestrian and bicycle factors. It has not yet secured any funding but merits support. This work could be readily conducted in the Boston region, where there is growing local government support for traffic calming and other strategies supportive of non-motorized transportation. Moshe Ben-Akiva and John Bowman presented a paper at the 1995 Transportation Research Board (TRB) Annual Meeting on his activity based modeling research and model development, which has been widely praised as innovative and practical.[21] This pedestrian/bicycle work would build on that new framework, which is at the cutting edge of applied regional modeling.

- **Denver, Colorado.** The City of Boulder, Colorado, and the Denver Regional Council of Governments (DRCOG) is another possible venue for such research, with a recent household travel survey for Boulder County that covers a portion of the region and exhibits wide variation in bicycle and pedestrian travel and conditions, with very high non-motorized travel rates in central Boulder. DRCOG has a GIS but has not evaluated pedestrian and bicycle friendliness factors. DRCOG plans a new regional household travel survey in 1996, since one has not been conducted for many years. Following this survey, DRCOG plans to develop a new generation transportation modeling system. Work in this region would likely be firmly rooted in the classical four-step modeling approach, but might bring in some of the concepts of activity analysis after a new regional travel survey has been undertaken and processed in 1996-97.

B. Quick-Response Models Sensitive to Pedestrian and Bicycle Travel Factors

Most U.S. communities lack the modeling tools and data for development of state-of-the-art transportation models sensitive to non-motorized travel factors. While they could and arguably should invest in expeditious development of such tools, the reality is that they will likely take several years to upgrade their current models to meet current best practices, which still fall quite short of what is needed for evaluation of pedestrian and bicycle programs and strategies. Thus, it is important for DOT/EPA to also support near-term quick-fix strategies for adjusting typical regional four-step computer transportation models to correct for their lack of sensitivity to pedestrian and bicycle travel factors.

Empirical measurement and analysis drawn from regions in North America and elsewhere exhibiting widely varying levels of non-motorized travel can reveal much about the range of response to different strategies in varying contexts. This quick-response approach would seek to adapt and synthesize available model coefficients from regions with models sensitive to pedestrian/bicycle travel factors, using logit model coefficient scaling.[22] This work could be complemented with other transferable parameters based on before/after evaluations and cross-sectional research studies. To support this approach, a survey should be undertaken of U.S., European, Canadian, Australian, and Japanese transportation models and research incorporating measures related to pedestrian/bicycle travel, building on limited research done to date.[23] This will provide one basis for quick-fix model development.

It would be most valuable for this work to consider also the interactions of pedestrian/bicycle travel factors with related and potentially supportive strategies, including:

- improvements to the quality of the pedestrian and bicycle environment, traffic calming, development of traffic cell systems, comprehensive bicycle network development;
- improved bicycle and pedestrian access to and from public transportation;
- market-based pricing strategies, including electronic road pricing, pay-by-the-mile automobile insurance and VMT-based registration fees, parking management; and commuter choice programs;
- growth management and land use policies, including encouragement of transit oriented development, accessory apartments for infill, and greater pedestrian proximity to convenience retail services.

Consideration of these interactions can be accomplished only by integrating walking and bicycling into the full regional model structure. However, experience from other regions and sensitivity tests using models from other regions can provide the basis for estimating likely changes from baseline conditions for specific areas.

Because local data on pedestrian/bicycle travel and conditions are not widely available (indeed, regional travel surveys commonly have ignored or undersampled non-motorized travel), it is important to also explore how universally available data can be used to devise quick response methods. "Quick-fix" modeling techniques should be grounded in baseline estimates of current conditions, preferably at the traffic zone or census tract level. Surrogate factors could be correlated with pedestrian/bicycle travel to establish estimated baseline conditions for pivot point modeling, where local data are limited. For example, the data for housing unit construction and residential density can be drawn directly from Census Public Use Microdata Samples (PUMS). Census TIGER file data can provide measures of network connectivity and density. The National Personal Transportation Survey (NPTS) can provide microsample travel survey data for non-work travel which can be linked to PUMS data using statistical inference for quick development of microsimulation modeling tools where regional travel survey data are lacking. Census Journey-to-Work data can provide additional data on work travel mode shares and other aggregate travel characteristics by small areas, with larger sample sizes.

Integrating these universally available data elements can provide a framework for development of potentially transferable regional microsimulation models sensitive to transportation pricing and pedestrian/bicycle friendliness, building on earlier work by Greig Harvey in California, Chicago, and elsewhere.[24] Indeed, Michael Replogle and Greig Harvey are in the earliest stages of a collaboration to explore such links in the New York metropolitan region, in cooperation with the New York Metropolitan Transportation Commission (NYMTC), the region's Metropolitan Planning Organization. An application for limited funding for this work is pending; additional support would be most valuable to support more extensive examination of pedestrian/bicycle travel factors in the NY region. NYMTC itself continues to work with an early 1970s vintage highway model that is generally insensitive to transit, walking, and bicycling, but has extensive work underway to develop a large regional household travel survey in fall 1995 or spring 1996 to support development of a new multi-modal regional transportation model. Michael Replogle is a member of NYMTC's transportation modeling advisory committee and Greig Harvey is a member of the consultant team for the larger NYMTC modeling effort being carried out by Parsons Brinckerhoff Quade and Douglas.

This effort might seek to develop and document in a relatively short time a new and potentially transferable regional model sensitive to the effects of changes in pedestrian/bicycle factors and other transportation system elements on motor vehicle use. This could be coded as a spreadsheet logit model for pivot point analysis, accompanied by case study documentation, or as a set of macros that could work with commercially available transportation modeling software packages. These quick-fix techniques might then be transferred to several other regions where they might find the greatest utility, and this experience might be documented for further dissemination. The New York metro area would be a good venue in which to develop and demonstrate these tools, given current opportunities, needs, and data constraints.

It may also be useful to consider other regions that present potentially promising opportunities for advanced or quick-fix model development or to demonstrate how techniques can be successfully transferred between regions. Cooperative agreements and small pilot grants to local governments, MPOs, state DOTs, universities and non-governmental organizations, as well as targeted contract technical assistance could be a catalyst for progress in these regions. Such opportunities might include Chicago, where work could build on the effort now being done for the RTA; northern New Jersey, where a Route 1 Transportation Collaborative project is getting underway and might focus on enhanced evaluation of pedestrian/bicycle strategies; one or more cities in Florida, where the State DOT has been working for years to improve pedestrian and bicycle conditions and also supports a statewide travel model; Montgomery County, Maryland, where extensive survey and GIS data sets have been developed but not fully exploited; or other regions.

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